(12) UK Patent Application (19) GB (11) 2 360 659 (13) A

(43) Date of A Publication 26.09.2001

(21) Application No 0006697.7

(22) Date of Filing 20.03.2000

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(51) INT CL[7]
H04N 1/32

(52) UK CL (Edition S)
H4F FBB F22

(56) Documents Cited
EP 0901282 A2 EP 0725529 A2

(58) Field of Search
UK CL (Edition R) H4F FBB
INT CL[7] G06T 1/00, H04N 1/00 1/32 5/913
ONLINE: WPI; JAPIO; EPODOC; INSPEC

(54) Abstract Title
Watermarking in the luminance component of a picture signal

(57) By deriving a luminance component substantially unaffected by gamma correction, and/or chrominance components, watermarking techniques which can be used to embed a watermark in a conventional (gamma correction affected) luminance component can be enhanced, as the embedding may better reflect the way detail is perceived by the eye.

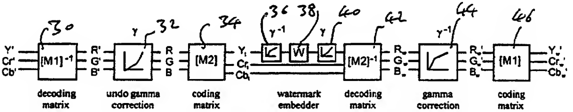

Figure 2

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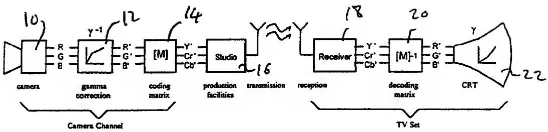

Figure 1

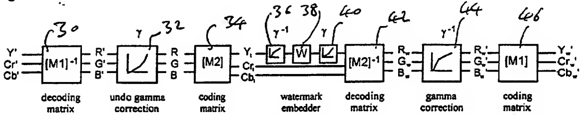

Figure 2

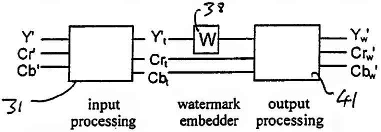

Figure 3

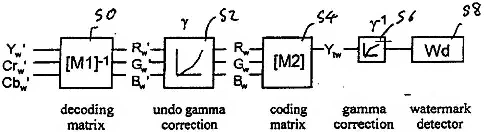

Figure 4

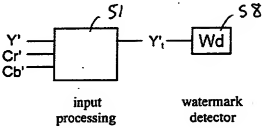

Figure 5

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WATERMARKING

The present invention relates to a method of embedding a watermark in a picture. The present invention is particularly, but not exclusively, applicable to embedding of a watermark in a moving picture signal, such as a television signal.

It is known to embed a watermark in a picture (moving or still). The principle is that a signal is applied in such a way or at such a level that it is not readily detectable to a casual observer or to the naked eye but can be detected by equipment or an algorithm designed to find the watermark. The embedding of a watermark can assist in detecting unauthorised copies or corruption of data, and can also be used to carry data. Most usually, a watermark is embedded by modifying pixel values of a digitized representation of a picture in accordance with a predetermined algorithm; different methods of watermarking tend to differ in the algorithms used, but almost invariably take as a starting point a similarly digitized image. Particularly advantageous methods of embedding a watermark are disclosed in our earlier UK patent application numbers 9906299.4, 9926530.8 and 9930353.9 and in our UK application being filed herewith claiming priority from those applications and bearing reference GB0006696.9 IK/21302, a copy of which is being filed as an appendix to this application, the entire disclosure of which is hereby incorporated herein by reference.

Existing systems, particularly our earlier system, can work well. However, pursuant to the present invention, a method of embedding a watermark has been proposed which can improve robustness of a watermark or reduce the likelihood of an unauthorised party successfully erasing, detecting or tampering with the watermark.

In a first aspect, the invention provides a method of applying a watermark to a picture comprising deriving a luminance component from the picture

substantially unaffected by gamma correction and applying a watermark to the luminance component.

Thus it can be seen that the invention differs from existing methods primarily not in the basic algorithm used for embedding the watermark, but by taking a different starting point for application of the watermark. Indeed, the invention is complimentary to and can be used to advantage in conjunction with existing methods which can be used to embed a watermark in an essentially monochrome signal, such as those described in our earlier applications.

To assist in understanding the effect of the invention, and by way of initial background (explained more fully below) colour television signals have generally been converted into luminance and chrominance components for transmission, the luminance component generally being transmitted at a higher bandwidth than the chrominance component. A camera typically has red, green and blue colour sensors and the luminance and chrominance signals are derived from these but to compensate for non linearities in the way cathode ray tubes (CRTs) display signals, it is normal to gamma correct the red green and blue signals prior to conversion into luminance and chrominance components. It had been recognised that, due to this gamma correction, some of the luminance information was carried in the chrominance signal and, as a result, suffered some degradation and to compensate for this, it had been proposed to introduce so-called constant luminance transmission techniques in which the luminance signal carries all the genuine luminance information. For practical reasons, such transmission techniques were not been commercialised and the research therefore dropped from the mainstream of thinking in the industry, particularly with the advent in recent years of digital television.

Surprisingly therefore, pursuant to the invention, previously unfruitful considerations directed to transmission of analogue television signals are applied to advantage in the unrelated field of watermarking images. It should be noted

that this application is independent of the nature of the images, in particular it does not necessarily require the images to have been previously coded into luminance and chrominance components and the derivation of the "constant luminance" signal does not necessarily affect the way the picture signal may be transmitted but instead the way in which the watermark is embedded in the picture.

Whereas constant luminance techniques were considered for transmission primarily to improve fidelity of colour signals, this is not of direct concern in the field of watermarking, but surprisingly the application to the present invention may provide a number of different advantages. Firstly, since the embedding process is better matched to the way the eye sees detail, it becomes easier to optimise the watermark energy which can be embedded whilst remaining invisible. Secondly, since many watermarking techniques rely on relatively low frequency components in the video signal to carry the watermark (since this improves robustness against digital compression), the part of the watermark which travels in the chroma channels also survives attacks well, and can contribute to more reliable detection. Thirdly, any hostile attack will have to be more complex if it is to have the same effect on the CL watermark as it would on a conventional watermark.

It is to be noted that, although described in the context of television signals, and signals commonly associated with analogue transmission of television, the invention is applicable in general to pictures irrespective of the transmission format and the same principles may be applied using digital signal processing techniques to a digital moving or still picture. Of course, the invention is more conveniently applied to a signal which is, or is likely to be, broken down into luminance and chrominance components. Whilst the principles are applied to colour signals, it will be appreciated that the method does not rely on the picture itself having any colour component.

Preferably, deriving the luminance signal comprises undoing a gamma correction applied to an existing picture, and the gamma correction is re-applied after embedding the watermark. Normally gamma correction is applied at an early stage in signal processing, typically in a camera, but, of course, if the signal concerned has not previously been gamma corrected, it will not be necessary to undo the gamma correction.

The method may include coding input colour component (e.g. RGB) signals substantially free of gamma correction into chrominance and luminance signals, applying the watermark to the luminance signal and re-coding the watermarked luminance signal and the chrominance signals to generate output colour component (RGB signals), the method preferably further comprising gamma correcting the output colour component signals, and preferably further comprising coding the output colour component signals to chrominance and luminance signals.

The invention extends to apparatus and computer program products embodying such methods, as well as to watermarked pictures and signals. Further aspects of the invention and preferred features are set out in the claims, to which reference should be made.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings in which:-

Fig. 1 is a schematic diagram of a conventional television channel;

Fig. 2 is a schematic diagram of a constant luminance watermark embedder in accordance with a preferred embodiment of the invention;

Fig. 3 is a schematic diagram of a hardware implementation of the embedder of Fig. 2 having integrated input signal processing and integrated output signal processing;

Fig. 4 is a schematic diagram of a watermark detector in accordance with

an embodiment;

Fig. 5 is a schematic diagram of a hardware implementation of the detector of Fig. 4 having integrated input signal processing and integrated output signal processing.

Before describing specific implementations, to assist in understanding the invention, since the background principles of early constant luminance work may not be familiar to those skilled in the art of watermarking, these will be explained, with reference to Fig. 1.

In a conventional TV system, as depicted in Fig. 1, a camera 10 initially provides an RGB output to a gamma corrector 12 (often integrated within the camera) which is passed to a coder 14 to produce conventional Luma and Chroma signals. These are processed in a studio 16 and transmitted over a broadcast network to a receiver 18 which initially derives luminance and chrominance signals (either by means of analogue demodulation of a carrier, for example using PAL modulation or from a digital signal such as an MPEG-2 decoder). These are then decoded into RGB signals by decoder 20 and passed to display 22 such as a CRT; this inherently has a non-linear response, so inherently undoes the gamma correction (a display such as a plasma display, which has a linear transfer characteristic, is generally provided with an electronic gamma correction).

Luminance is that proportion of what the eye sees which contains the brightness and all the high-frequency detail information. It is the "black-and-white" information in a picture. Colour (chrominance) can be added to a picture at lower resolution thanks to the lower resolution of the eye to these components of the picture information, as discussed in The Reproduction of Colour, 5th Edition, Hunt 1995, Fountain Press, the entire disclosure of which is incorporated herein by reference.

For the sake of bandwidth efficiency, TV systems try to mimic the way

the eye handles these components, and so the Chroma signals (Red and Blue colour-difference signals, known as Cr and Cb) can be carried at lower resolution than the Luma (Y).

We use the terms Luma and Chroma to describe these components of a TV system since they are not true Luminance and Chrominance, which are defined in terms of the human eye's response to the picture. The result of the failure of current TV systems to observe "Constant Luminance" (CL) principles results in some Luminance information being carried in the Chroma channels. Because the Chroma channels have a reduced bandwidth (and in digital compression, are subject to a further reduction in resolution) that portion of the Luminance signal which travels in the Chroma channel suffers visible degradation. A TV system following CL principles is feasible, but has never been adopted due to the practical difficulty of implementing such a system in the presence of existing non-CL systems. A system using such principles was proposed approximately a decade ago by Roberts in BBC Research Department Report 1990/2 entitled "HDTV - A chance to improve television colorimetry". The principal difference between conventional TV systems and CL systems is in the placing of the gamma correction in the chain.

Gamma correction is a non-linear process by means of which the TV signal is pre-conditioned before transmission such that when the signal is applied as a voltage to the Red, Green and Blue (RGB) guns of a cathode ray tube (CRT), the resulting light output obeys a linear overall transfer characteristic. This pre-conditioning (gamma-correction) is approximately a power law, and has the added benefit of being well matched to give equal visibility to noise and quantisation across the whole range of the signal.

In a conventional TV system, for example as shown in Figure 1, the gamma correction (γ^{-1}) must be done on the RGB signals, since it is in the RGB space that the reverse process occurs actually in the CRT itself. The gamma

correction in the camera is not a pure power law, but that in the CRT is. The R'B'G' signals (the prime representing gamma-correction) are converted to Y'Cr'Cb' for transmission for the bandwidth efficiency reasons explained above.

In a proper constant luminance system, the luminance channel must be generated from the RGB before gamma correction, to ensure that none of the luminance information is carried in the chroma channels with their limited resolution. In a conventional broadcasting environment however, this has been impractical due to the costs of the matrixing operations and gamma conversions which would be required in every receiver. Thus, as noted above, the principles have not been commercially implemented in a receiver.

An embodiment of the invention will now be described which applies the principles mentioned above to the seemingly unrelated problem of reliably embedding a watermark in a picture, with reference to Figure 2 which shows a schematic diagram of a CL Watermark embedder. The input and output are conventional Luma and Chroma signals as are used in existing broadcast environments. The subscript (t) indicates a signal generated according to "True" (Constant) Luminance principles. The matrices [M1] and [M1]-1 are those applicable to the TV system being used. For example in the existing TV systems in general use across the world (ITU-R BT.601) the matrix [M1] is given by:

$$[M1] = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.5 & -0.419 & -0.0813 \\ -0.169 & -0.331 & 0.5 \end{bmatrix}$$

If the system is coded according to Rec.BT 709 standards, Matrix [M1] is given, approximately, by:

$$[M1]_{709} = \begin{bmatrix} 0.213 & 0.715 & 0.0722 \\ 0.5 & -0.454 & -0.0458 \\ -0.115 & -0.385 & 0.5 \end{bmatrix}$$

The above matrix values would also be used for [M2] in a Rec.709 system.

Matrix [M2] contains the Constant Luminance coding equations, which are dependent on the colour primaries of the specific system. For EBU primaries, with linear chroma coding, this matrix is:

$$[M2] = \begin{bmatrix} 0.222 & 0.7067 & 0.0713 \\ 0.778 & -0.7067 & -0.0713 \\ -0.222 & -0.7067 & 0.9287 \end{bmatrix}$$

In an NTSC system, using SMPTE-C primaries and white point at D65, [M1] is as above. The following values for [M2] may be used. Since chrominance equations are not defined for a constant luminance NTSC system, Cr = r - y, Cb = b - y have been used.

$$[M2]_{SMPTE} = \begin{bmatrix} 0.212 & 0.701 & 0.0866 \\ 0.788 & -0.701 & -0.0866 \\ -0.212 & -0.701 & 0.913 \end{bmatrix}$$

The gamma (γ) of CRTs has been ascribed values of between 2.2 and 2.8 (a preferred range) for TV systems across the world, but more recent measurements with improved techniques suggest that a value of about 2.35 (a preferred value) is an accurate measure of the value of gamma for modern CRTs. Gamma correction may be applied and undone according to the following

equations, which mimic the final transfer characteristic of the CRT, rather than that of the pre-correction in the camera:

$Y' = Y^{1/\gamma}$ (Gamma Correction) and $Y = Y'^{\gamma}$ (undo Gamma Correction)

In a practical system, the matrix operations and gamma manipulations may advantageously be rolled into a single signal processing operation incorporating the techniques described above. Thus a preferred hardware implementation is shown schematically in Figure 3.

Alternatively, the watermark embedder itself may incorporate some of the processing, such as the gamma correction of the luminance channel, or this particular step might even be avoided by suitable choice of non-linear luminance-level dependency in the embedded watermark, applied to the linear Y_t.

A compensatory delay, equal to that introduced by the watermark embedder W, should be introduced in the Cr_t and Cb_t signal paths to maintain synchronisation. For simplicity, this is not shown in Figures 2 or 3.

A preferred practical implementation of such a system makes use of inputs and outputs in the form of serial video data streams, with Y', Cr' and Cb' multiplexed together, as is commonly found as an interconnection standard on broadcast equipment, such as conforming to ITU-R BT.601-4.

The method may be applied to still (for example scanned) or computer generated images. Normally, computer generated or scanned images are manipulated in RGB space, although this is not necessarily so. Such images are normally gamma corrected, for example most scanning packages will apply a gamma correction to an image on scanning so that it will be displayed correctly, but again this is not necessarily so. The invention may be applied to such

images. As will be appreciated, for example with reference to Fig. 2, an RGB image can be converted to chrominance and luminance (by a method equivalent to multiplication by matrix M2), normally after undoing an existing gamma correction, and the watermarked signal may be converted back to RGB space. Thus, effectively, an RGB signal may be processed by an implementation equivalent to that depicted in Fig. 2, omitting the initial decoding and final coding matrices $[M1]^{-1}$ and [M1].

Thus, even if the signal is an RGB signal, intended to be displayed as an RGB signal, it may be convenient to convert it to luminance and chrominance components and to apply a watermark to the luminance component, rather than using a known method suited for watermarking RGB signals directly.

In certain cases, both for RGB images and for chrominance and luminance images, the signal processing may be integrated, for example by means of look-up tables or signal processing algorithms which have the effect of applying the watermark to a luminance component as described above, without necessarily producing an identifiable luminance signal. Thus the step of deriving the luminance component, as mentioned above and as claimed, may be implicit in signal processing rather than explicit. It will be appreciated that, by considering the effects of each processing step depicted in Fig. 2, it is possible to derive a relationship between output colour component signals and input colour component signals or even to derive a relationship between input luminance and chrominance and output luminance and chrominance values. Due to the non-linear nature of the interaction between the gamma correction and matrix transformations, this will not be a simple linear formula, but can be applied directly, or by means of empirically defined formulae, look-up tables, approximate formulae or iterative methods, so that it is possible to apply a watermark to chrominance and luminance or RGB (or other colour component values) to have the effect of applying the watermark to a luminance component as described above, without actually deriving the luminance component. This

may be appropriate if the watermarking algorithm is relatively simple, for example adding or subtracting a fixed number or fixed proportion of the luminance of each pixel.

Since the watermarked pixel value may be a function of several luminance values, however, it may nonetheless often be useful explicitly to determine and store or output such luminance values, or closely related values, for at least a portion of the picture. For example, in the methods described in our earlier applications, the watermarking process takes into account local variance to determine a measure of local visibility, so several luminance values are required.

If a watermark has been added to a video signal in the manner described in section 3 above, it will be advantageous, both for reliability of data transmission and resistance to attacks on the watermark, to make use of Constant Luminance techniques in the watermark detector (although this is not essential).

Figure 4 shows a schematic diagram of a CL Watermark detector. The input is conventional Luma and Chroma signals as are used in existing broadcast environments.

The matrices $[M1]^{-1}$ and [M2], and gamma (γ) are as described above.

In a practical system, the matrix operations and gamma manipulations may be rolled into a single signal processing operation incorporating the techniques described above. Thus a preferred hardware implementation is shown in Figure 5.

In the above description, preferred features and implementation details may be provided independently of other features, unless otherwise stated. The appended abstract is incorporated herein by reference.

Claims

1. A method of applying a watermark to an input picture signal, the method comprising deriving a luminance component substantially unaffected by gamma correction from the input picture signal and applying a watermark to the luminance component to generate a watermarked signal.

2. A method according to Claim 1 or 21, wherein deriving the luminance component includes applying an inverse gamma correction substantially to cancel a previous gamma correction applied to the picture.

3. A method according to Claim 1 or 2, wherein the method includes coding colour component signals to chrominance and luminance signals.

4. A method according to Claim 3 as dependent on Claim 2, wherein the inverse gamma correction is applied prior to said coding.

5. A method according to Claim 3 or 4, wherein the colour component signals are decoded from input chrominance and luminance signals.

6. A method according to Claim 1 or any claim as dependent thereon, further comprising gamma correcting the watermarked signal to generate an output picture signal.

7. A method according to Claim 6, including decoding the watermarked signal to colour component signals, said gamma correcting being applied to the colour component signals.

8. A method according to Claim 7, wherein the colour component signals are coded to chrominance and luminance components forming said output picture

signal.

9. A method according to any preceding claim, wherein the input picture signal is a motion video signal.

10. A method according to any of Claims 1 to 8, wherein the input picture signal is a still picture, preferably a digital still picture.

11. A method according to Claim 9, wherein the input picture signal is a digital signal, preferably a serial video data stream, preferably conforming to Rec 601 or Rec 709.

12. A method according to Claim 11, wherein the input picture signal is compressed, preferably MPEG compressed.

13. A method according to Claim 1 or any claim dependent thereon, wherein the watermark is added non linearly to the luminance component.

14. A method according to Claim 1 or any claim dependent thereon, wherein adding the watermark comprises applying a gamma correction to the luminance signal, embedding the watermark, and applying an inverse gamma correction to the watermarked luminance signal.

15. A method according to Claim 1 or any claim dependent thereon including deriving chrominance components to be recombined with the watermarked luminance component to provide the watermarked signal.

16. A method according to Claim 15, wherein the chrominance components are delayed or stored for an amount of time corresponding to the delay introduced in the luminance component by applying the watermark.

17. A method according to any preceding claim performed by means of digital signal processing.

18. A method according to Claim 3, 5 or 7, or any claim as dependent thereon, wherein the colour component signals comprise RGB signals.

19. A method according to any preceding claim, wherein signals are converted between colour components and luminance and chrominance components by a process corresponding to matrix multiplication by a predetermined matrix.

20. A method according to any preceding claim wherein the input signal or the output signal, preferably both, comprise Luma and Chroma components conforming to a broadcast standard.

21. A method of detecting a watermark in an input picture signal comprising deriving a luminance component substantially unaffected by gamma correction from the input picture signal and testing for a watermark in the luminance component.

22. A method according to Claim 21 or any claim dependent thereon, including applying a gamma correction to the luminance component prior to said testing.

23. A method according to any preceding claim, wherein the watermark is embedded or detected by means of a method or apparatus substantially as any one described in or as claimed in our International patent application bearing reference IK/21302 WO 00/56058 being filed concurrently herewith and claiming priority from UK patent application numbers 9906299.4, 9926530.8 and 9930353.9, the content of which is annexed hereto and incorporated herein by reference.

24. Apparatus or a computer program product arranged to perform a method according to any preceding claim.

25. A watermark embedder comprising input signal processing means for deriving a luminance component substantially free of gamma correction from an input picture signal, watermarking means for applying a watermark to said luminance component and output signal processing means for producing an output signal from the watermarked luminance component.

26. Apparatus or a computer program product arranged to perform a method according to Claim 21 or any claim dependent thereon.

27. A watermark detector comprising input signal processing means for deriving a luminance component substantially free of gamma correction from an input picture signal and watermark detecting means for detecting a watermark in said luminance component.

28. A method according to Claim 1, wherein said luminance component signal substantially free of gamma correction is explicitly derived and stored or output.

29. A method according to Claim 1, wherein deriving said luminance component signal substantially free of gamma correction is incorporated in a signal processing step taking as an input (a) luma and chroma components affected by gamma correction or (b) colour component signals, preferably gamma corrected and providing as an output (a) luma and chroma components affected by gamma correction or (b) colour component signals, preferably gamma corrected.

30. A method of applying a watermark to an input picture analysable into a luminance component substantially free of gamma correction and chrominance components, the method comprising applying the watermark to the input picture

to produce an output picture in which the watermark has been applied to the luminance component substantially without affecting the chrominance components.

31. Apparatus according to Claim 25, wherein the luminance component signal substantially free of gamma correction is explicitly derived and stored or output by the input signal processing means.

32. Apparatus according to Claim 25, wherein said input and output signal processing means are provided by integrated signal processing means arranged to effect watermarking of said luminance component without outputting the luminance component.

33. Apparatus according to Claim 32 wherein the integrated signal processing means is arranged to take as an input (a) luma and chroma components affected by gamma correction or (b) colour component signals, preferably gamma corrected and to provide as an output (a) luma and chroma components affected by gamma correction or (b) colour component signals, preferably gamma corrected.

34. Apparatus for applying a watermark to an input picture analysable into a luminance component substantially free of gamma correction and chrominance components, the apparatus comprising signal processing means for applying the watermark to the input picture to produce an output picture in which the watermark has been applied to the luminance component substantially without affecting the chrominance components.

35. Apparatus according to any of Claims 25 to 27 or 31 to 34, comprising a digital signal processor.

36. Apparatus substantially as any one herein described or as illustrated in

Figs. 2 to 5 of the accompanying drawings.

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Application No:	GB 0006697.7	**Examiner:**	Frank D. Moeschler
Claims searched:	1-36	**Date of search:**	19 October 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H4F (FBB)

Int Cl (Ed.7): G06T-1/00; H04N-1/00, 1/32, 5/913

Other: ONLINE: EPODOC: JAPIO: WPI: INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	EP 0901282 A2 (HITACHI) See Col 14 especially	1,9-13,17 20,21,24-27, 30,35
X	EP 0725529 A2 (IBM) See Col 6 especially	1,9-13,17 20,21,24-27, 30,35

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.